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OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT
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TESTS OF FOUR MODELS OF THE 5" SSR ROTATING ROCKET

THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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OF THE
5" SSR ROTATING ROCKET

ROBERT T. KNAPP

OFFICIAL INVESTIGATOR

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRODYNAMICS LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr207-2239

Laboratory No. ND-33

Report Prepared by
Harold L. Doolittle
Hydraulic Engineer

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FIG. 1 - ROCKET MODEL NO. 32

FIG. 2 - ROCKET MODEL NO. 20

TESTS OF FOUR MODELS
OF THE
5" SSR ROTATING ROCKET

GENERAL

This report covers tests made on a 2-inch diameter model of the 5" spin-stabilized rocket. The tests were conducted at the Hydrodynamics Laboratory of the California Institute of Technology, and were authorized by a letter of January 31, 1944 from Dr. E. H. Colpitts, Chief of Section 6.1, National Defense Research Committee.

The purpose of the tests was to determine the performance of the rocket with various nose shapes and variations in body dimensions. Four different models were tested, the same afterbody being used in all cases.

The attached appendix gives definitions of the terms used in this report, as well as other pertinent data.

This report deals only with the static stability of the projectile without rotation. Since it is not possible to operate the water tunnel at velocities equivalent to supersonic velocities in air, the data herein are applicable to the projectile in the first stages of flight only.

DESCRIPTION

Figures 1 and 2 are photographs of Models Nos. 32 and 20. Figure 3 gives outline drawings of the projectile showing the four models that were investigated. The lengths of the four models are practically the same (approximately 29 to 31 inches), the nominal diameter being 5 inches. All models are fitted with the same afterbody. The following approximate data pertain to the four models of this rocket.

Model No.	Maximum Diameter	Weight Loaded	Weight in Flight	Velocity
20	5 in.	49.7 lbs	39.6 lbs	1500 ft/sec
32	5	51.4	41.3	1500
25	5	49.9	44.3	800
21	5	48.3	42.7	800

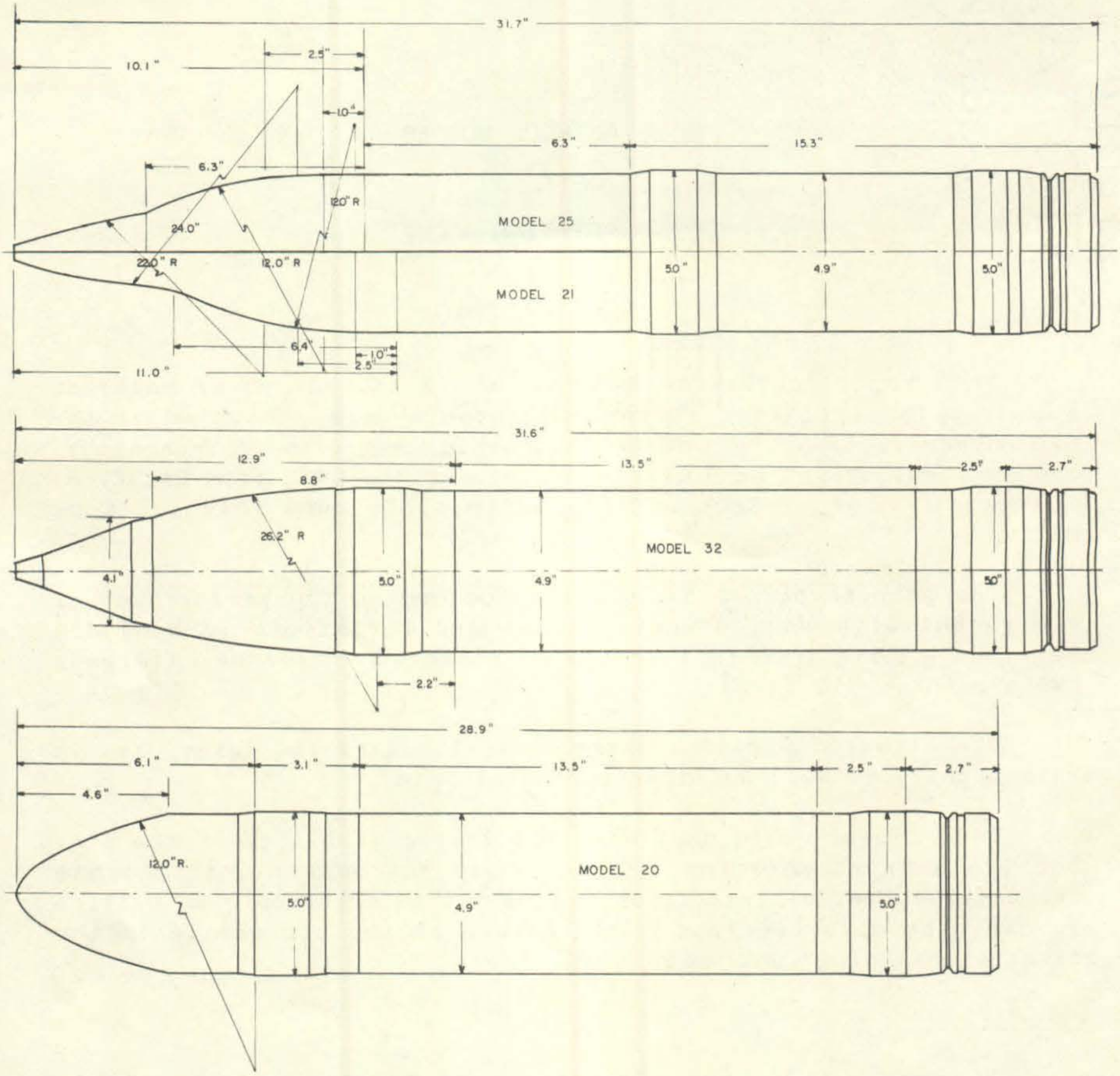


FIG. 3 — OUTLINE DRAWINGS OF PROJECTILE SHOWING THE FOUR MODELS

PERFORMANCE CHARACTERISTICS

The force coefficient curves for the four models are shown in Figure 4. As can be seen, there is not a great difference in performance of the various models. Model No. 20 has the highest drag, and Model No. 32 the lowest destabilizing moment.

'It is also noticeable that all models have very small destabilizing moments for angles of yaw less than 1 degree. This is a phenomenon often noticed with bullet-shaped projectiles; in fact, with some projectiles there is a slight stabilizing moment at very small yaw angles.

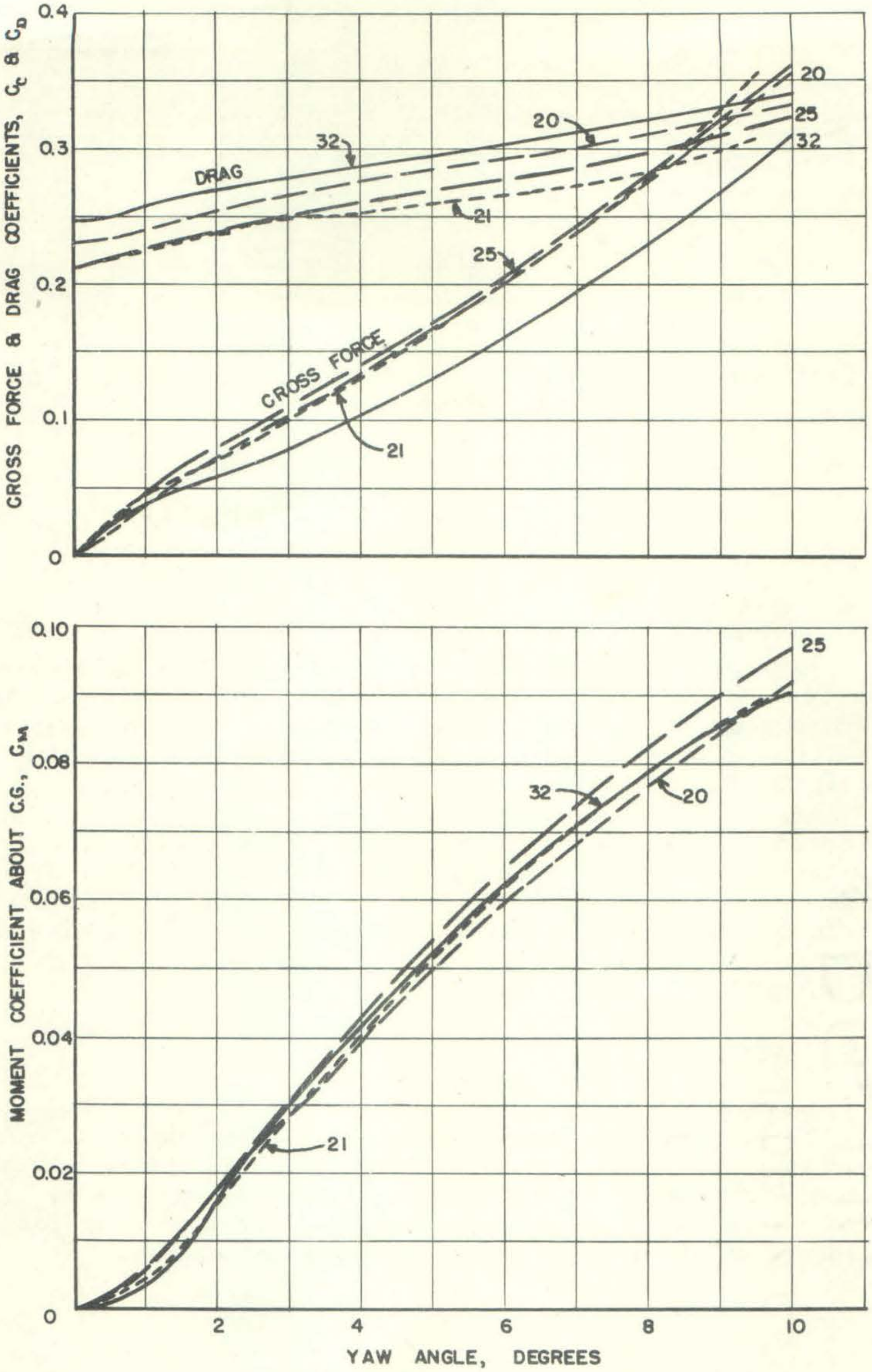


FIG. 4 — MOMENT, CROSS FORCE, AND DRAG COEFFICIENTS OF THE FOUR MODELS

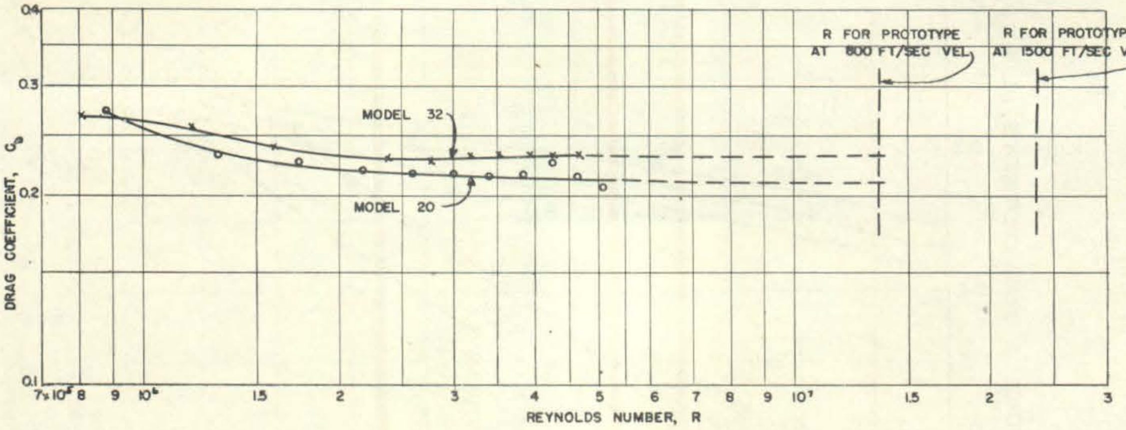


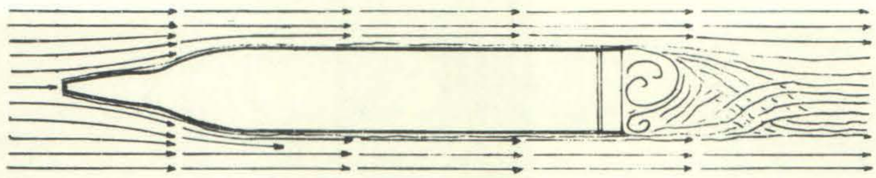
FIG. 5 – DRAG VS. REYNOLDS NUMBER
MODELS NO. 20 AND NO. 32

DRAG VS. REYNOLDS NUMBER

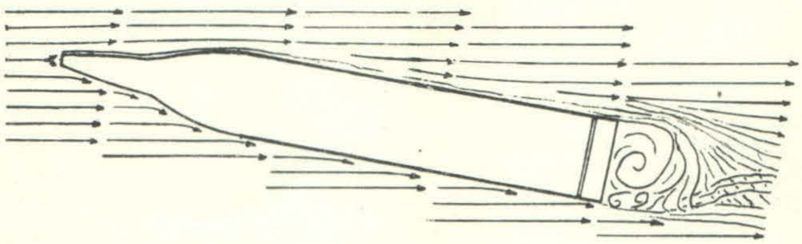
Runs were made on Models No. 20 and No. 32 to determine the variation in drag with Reynolds number. The results of these tests are shown in Figure 5. For the higher Reynolds numbers it is seen that the drag of Model No. 32 is about 7% higher than that of Model No. 20. In order to find the drag for the prototype, the model drag vs. Reynolds number curve can be extrapolatec to prototype speed. As the water tunnel tests are significant only for equivalent speeds corresponding to subsonic speeds of the prototype in air, the drag coefficient for a prototype velocity of 800 ft/sec is 13.5×10^6, and as seen in Figure 5, the drag coefficient at this value of R is 0.21 for Model No. 20, and 0.23 for Model No. 32.

FLOW LINE DRAWINGS

Figures 6 and 7 are flow line drawings of Models No. 21 and No. 25, respectively. These were made by close observation of the flow lines about the model in the Polarized Light Flume. There is little disturbance about the streamlined nose, but, as is always the case with bullet-shaped projectiles, there is considerable disturbance in the wake of the square-ended afterbody.

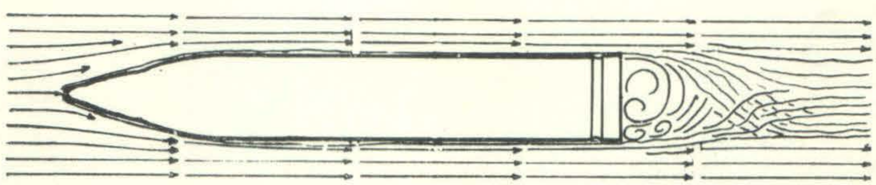


YAW = 0°

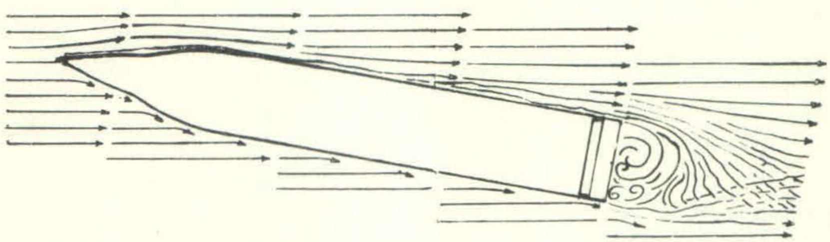


YAW = 10°

FIG. 6 — FLOW LINE DRAWING FOR MODEL NO. 21



YAW = 0°



YAW = 10°

FIG. 7 — FLOW LINE DRAWING OF MODEL NO. 25

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Locking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (−).

PITCH ANGLE, a

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (−) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (−) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAG, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (−). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (−).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle or pitch angle, and a stabilizing effect when the moment and yaw or pitch angle have opposite signs

NORMAL COMPONENT, N

The sum of the components of the drag and cross force (or lift) acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \tag{1}$$

or

$$N = P \sin \alpha + L \cos \alpha \tag{1a}$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

L = Lift force in lbs

ψ = Yaw angle in degrees

α = Pitch angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \tag{2}$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The force and moment coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \tag{3}$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \tag{4}$$

Lift coefficient, $$C_L = \frac{L}{\rho \frac{V^2}{2} A_D} \tag{5}$$

Moment coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \tag{6}$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

L = Measured lift force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \tag{7}$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{p_L - p_B}{\rho \frac{V^2}{2}} \tag{8}$$

in which

K = Cavitation parameter

p_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

p_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{V^2}{2g}} \tag{9}$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The cavitation parameter for incipient cavitation has the symbol K_i.

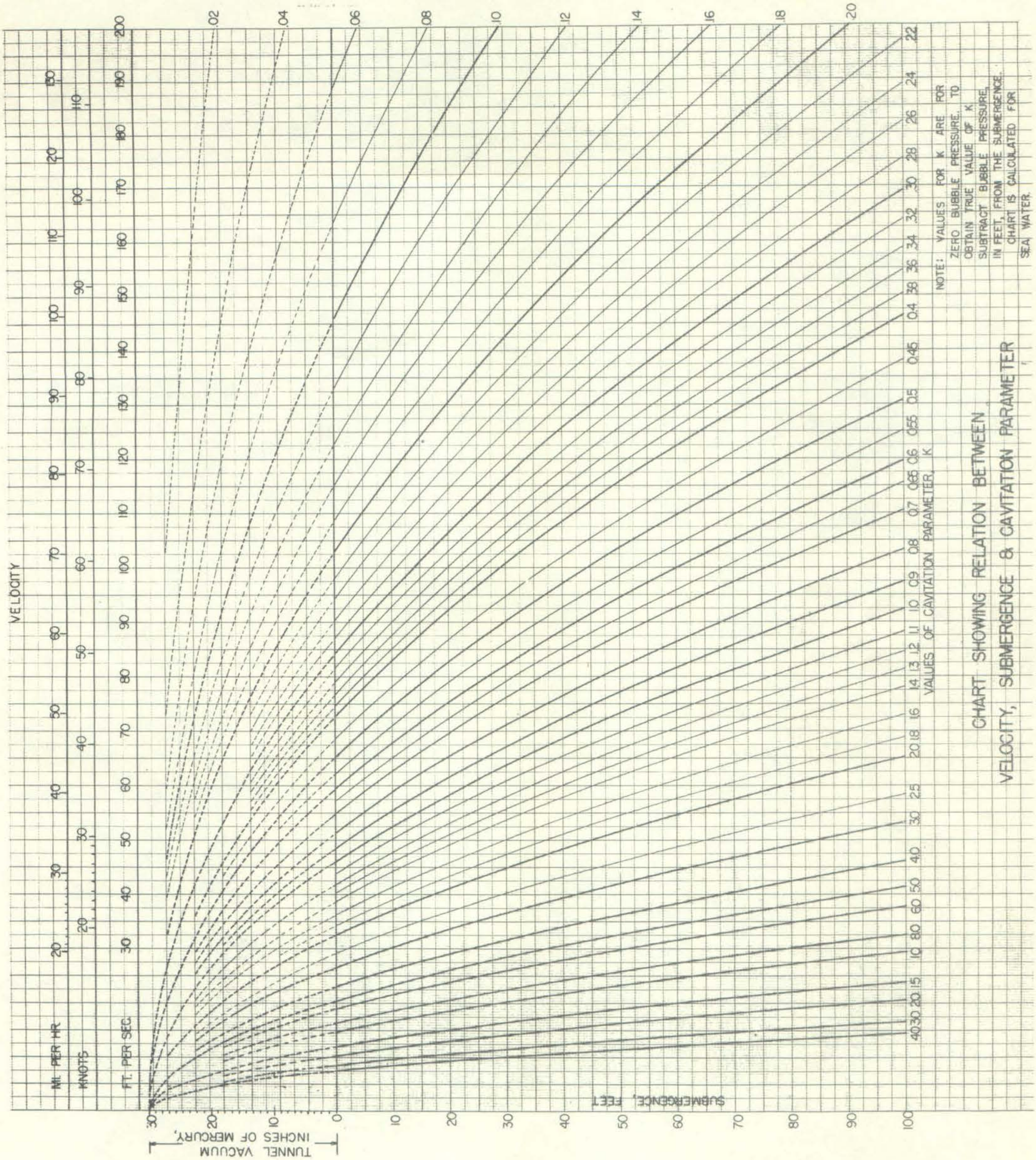
The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing amplitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability, or instability can be obtained from the center-of-pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.


VELOCITY
MI. PER HR.
KNOTS
FT. PER SEC.
SUBMERGENCE, FEET
TUNNEL VACUUM INCHES OF MERCURY,
VALUES OF CAVITATION PARAMETER, K
NOTE: VALUES FOR K ARE FOR ZERO BUBBLE PRESSURE. TO OBTAIN TRUE VALUE OF K, SUBTRACT BUBBLE PRESSURE, IN FEET, FROM THE SUBMERGENCE. CHART IS CALCULATED FOR SEA WATER.
CHART SHOWING RELATION BETWEEN
VELOCITY, SUBMERGENCE & CAVITATION PARAMETER